

PREDICTING HEAT FLUX IN PALM KERNEL SHELL REINFORCED BRAKE LINING USING MATLAB PDE TOOLBOX

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ABSTRACT

Frictional heat generated during braking application might lead to damaging effects such as thermal cracks, vibration, premature wear and brake fade. The brake material must be able to undergo high thermal stresses generated during repetitive braking. High amount of heat from braking must be absorbed and dissipated timeously to avoid damaging effects. The desire to improve the heat flow quality of organic based friction lining is motivated by the development of such lining using 0.212, 0.300, 0.425 and 0.850 mm grain sizes of pulverised palm kernel shell. Needed properties of such lining to be used in a derived partial differential equation were determined and the PDE Toolbox of Matlab used to analyse the heat flow in the samples. $S_{0.300}$ exhibited a high heat flux ($3.5 \times 10^8 \text{ W/m}^2$) showing it releases heat faster than its counterparts whose heat flux are in the same range of $2.5 \times 10^8 \text{ W/m}^2$. Intense heat flow through the brake system causes cooling which is necessary for components preservation.

KEYWORDS: Palm Kernel Shell, Friction Lining, Heat Flux & Matlab PDE Toolbox

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1. INTRODUCTION

The analysis of friction material performance through numerical method is on the rise with focus on thermal effects. Choi and Lee [1] investigated the influence of the material properties on the thermoelastic behaviour in disk brakes using finite element analysis. To obtain the numerical simulation of thermoelastic behavior appearing in disk brakes, the coupled heat conduction and elastic equations were solved with contact problems. Through the axisymmetric disc brake model, the thermoelastic phenomenon on each of the friction surfaces between the contacting bodies was investigated. The effects of the friction material properties on the contact ratio of the friction surfaces were examined and the larger influential properties were found to be the thermal expansion coefficient and the elastic modulus. Pressure distributions were more uniform in orthotropic disc brakes than the isotropic ones. The above work was later repeated by Rajesh [2] using the commercial finite element software package ANSYS (Analysis System) and his conclusion was same as that of his predecessor. LS-Dyna was used by Baranowski *et al*, [3] to numerically analyze thermo mechanical coupling in a brake. The phenomenon of heat generation by friction was emphasized during calculation and an approach to modeling wear of the brake pads using smooth particle hydrodynamic was implemented. It was observed that erosion criterion worked poorly and that the smooth particle hydrodynamic concept of numerically calculating wear process description may be modified in order to obtain results which are more accurate and equivalent to reality. Belhocine and Bouchetara [4] analysed the thermo mechanical modelling of dry contact between the brake disc and pads during the braking phase using ANSYS software. Unlike Choi and Lee [1] that used carbon-carbon

material disk in their analysis Belhocine and Bouchetara [5] used disk made of gray cast iron. It was observed that the temperature, Von Mises stress and total deformation of the disc and contact pressure of the pads increase as the thermal stresses are additional to mechanical stress which causes the crack propagation and fracture of the bowl and wear of the disc and pads. The commercial finite element software MATLAB has been used extensively in analysing disc brake systems [6 - 9]. Heat flux in brake system is an important characteristic which is yet to be fully understood because most methods of its measurement are usually cumbersome or impractical in real life.

Understanding heat flux in PKS based friction lining made of varying PKS powder will help determine the best suitable size for manufacture. In real-world applications one cannot know the exact heat flux at every point on the surface of a material, but approximation schemes can be used to calculate it. Matlab PDE Toolbox can be instrumental to achieve the desired results thus this study.

2. MATERIALS AND METHODS

Friction linings with various pulverized pks grain sizes as reinforcement were produced following the procedure described by Fono-Tamo and Koya (2017)[10]. Properties such as density, Poisson ratio, Young's modulus, thermal conductivity, specific heat and thermal expansion of the developed samples useful for the analysis were determined following standard methods as found in Fono-Tamo (2017) [11]. Based on the modified Matlab problem geometry in Figure 1 and various assumptions taken into consideration, a mathematical model Fono-Tamo (2017) [12] describing the thermal stress distribution in the brake lining in the form of a partial differential equation with the temperature at a position in the lining varying inversely with the cube root of its distance from the surface where braking force is applied was arrived at. The developed model was then applied in MATLAB based on the PDE Toolbox. PDE Toolbox already contains solution sets for Heat flow and Plain Stress problems, so that the required boundary conditions were set, PDE specifications made, meshing profiles defined and parameters solved.

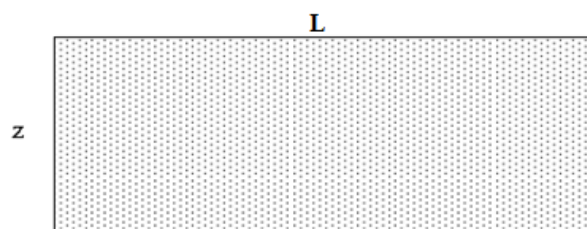


Figure 1

A numerical solution for heat flow using PDE Toolbox was conducted where the above geometry was considered. This same geometry was used here to visualise the z-axis cross section of the brake pad (surface-to-base cross section). The length (L) of the brake pad supported by Equation 1, was calculated based on the measured values of outer and inner radii of the palm kernel shell based brake pads, as well as its angle. The radii were 0.0725 and 0.1285 m respectively for the inner and outer radius while the angle was found to be 60°. The thickness of the samples was also measured and was found to be 0.01 m typically. The radii, the angle and the thickness were the same for all the samples.

$$L = \frac{\theta}{360} \pi (r_{out} + r_{in}) \quad (1)$$

In this analysis, all meshes were produced and 401 nodes and 704 triangles were created. The temperature was kept at 25 °C on all the outer boundaries, so the default boundary conditions had to change. The next move was to define

the PDE parameters after making sure to set the application mode to Heat Transfer in the PDE mode by double-clicking each of the two regions and entering the PDE parameters. Since this was in view to solve a parabolic heat equation, it was necessary to make sure that the parabolic option was selected.

In the rectangle region representing the geometry, values for density, heat capacity, and thermal conductivity were entered accordingly. So the time was set at 10 seconds. The initial value of the temperature was set to 25 °C. Since the boundary conditions and the initial value differ, the problem formulation contains discontinuities.

The PDE was solved and the heat flux distribution at the last time plotted. In order to best visualize the dynamic behavior the 3-D plot was turned on.

3. RESULTS AND DISCUSSIONS

The heat deformation plots show the deformed mesh of the brake pad cross-section after a heat load has been applied. The colour code shows bright yellow signifying high heat flux value that progresses to almost black colour for low value of heat flux as indicated in the legend. It was observed in the heat deformation plots that there is bending around the top edges, while the body of the brake pad appears to stretch and twist towards the bottom edges, such that there is a noticeable rift at the base. This is not strange, since materials are known to deform and twist under heat loading.

Although all the samples displayed the same characteristic of twisting and stretching, the $S_{0.212}$ (Figure (a)) displayed a heat flux value of $2.5 \times 10^8 \text{ W/m}^2$ along with $S_{0.850}$ (Figure (d)). $S_{0.425}$ (Figure (c)) with a heat flux value of about $3 \times 10^8 \text{ W/m}^2$ and $S_{0.300}$ displayed the highest ($3.5 \times 10^8 \text{ W/m}^2$), with the largest rift and the greatest degree of stretching and twisting.

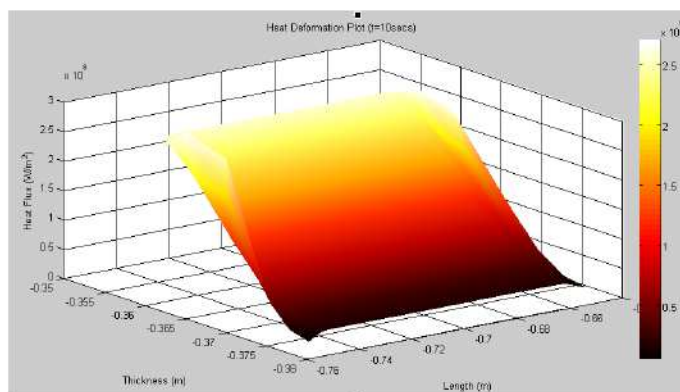


Figure 2 (a): Heat Flux plot for $S_{0.212} \text{ mm}$

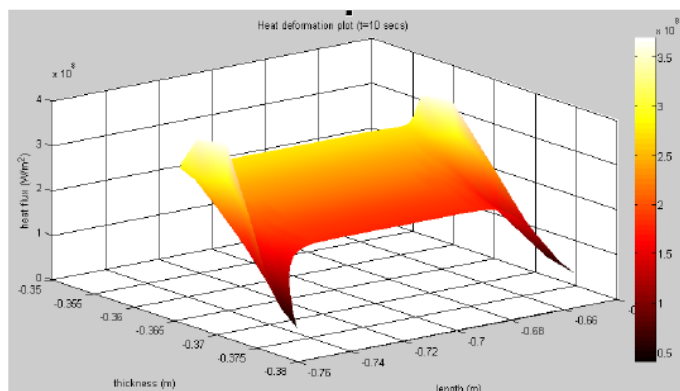


Figure 2 (b): Heat Flux plot for $S_{0.300} \text{ mm}$

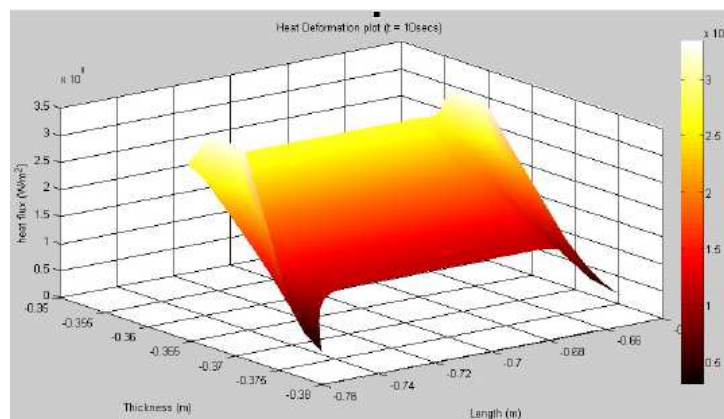


Figure 2 (c): Heat Flux plot for $S_{0.425\text{mm}}$

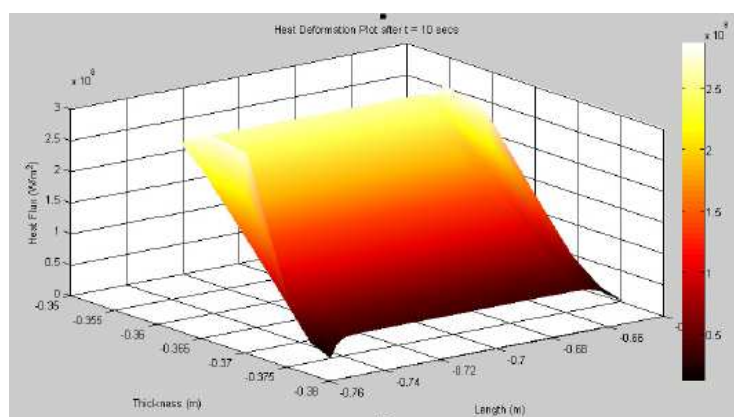


Figure 2 (d): Heat Flux plot for $S_{0.850\text{mm}}$

Figure 2

For most solids in usual conditions, heat is transported mainly by conduction and the heat flux is adequately associated with a temperature profile in a material with a certain thermal conductivity.

The bending and twisting of the brake pad occur under heat flux and the intensities depend on the rate of heat flux. The consequence is that brake squeal which is a phenomenon of dynamic instability that occurs at one or more of the natural frequencies of the brake system can be developed, creep leading to cracks and unsolicited noise on the brake pad surface can also occur. Edges of brake pads, as observed, whether leading or trailing edge, receive the brunt of heat generated and thus suffer more damage than the middle part of the pads. It is evident from the foregoing that high heat flux may influence the pad material negatively depending on the composition and structure. That is why in order to curtail this, some brake pad design have contrived slots on the surface (Talati and Talalifar, 2009) [13], some are made with friction blocks (Wang and Fu, 2013) [14] and some have their edges cut to an angle to increase air flow at the friction interfaces during braking application (Klasey, 2007) [15]. The developed PKS-based brake pads for the purpose of this study had contrived slots on the surface. It was observed that $S_{0.300}$ although with the highest heat flux value, exhibited much deformation under heat load. It is therefore important to have a controlled heat flux value in brake pads so the brake system will not suffer damages such as brake fade, premature wear, thermal cracks, brake fluid vaporization and thermally excited vibration to name a few.

4. CONCLUSIONS

Although thermochemical processes at the brake disc interface during operation still remain an area to be explored further, this work based on the behaviour of palm kernel shell reinforced friction lining shows that material properties such as specific heat and thermal conductivity play fundamental role in heat partitioning in such surfaces. It is concluded that the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment to avoid decreasing the friction coefficient between the disk and the pad and to avoid the temperature rise of various brake components and brake fluid vaporization due to excessive heating.

5. ACKNOWLEDGEMENT

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